marked asymmetry as is noted for the slow neutron fission of uranium may also be related to the supra-threshold energy at which the reaction occurs.

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Theoretical Evidence for the Existence of a Light-Charged Particle of Mass Greater than That of the Electron

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FROM theoretical considerations developed in a previous paper,[1] it can be deduced that particles with a charge equal to that of the electron and having a mass equal to 1.444 times that of the electron may be expected to exist.

It was shown that for an elementary charge the electrostatic potential

$$U=-(1/2K)\log[1-(2Ke/r)+(2K^2e^2/r^2)],$$

where e is the charge and K is a constant, satisfies the conditions that the integral of the charge density should be convergent and equal to e, and that the integral of the energy density should also be convergent. The value of the energy integral depends on that of K, and it also depends on the sign of e; the value is equal to

$$(e/4K)[(\pi/2)+1] \quad \text{or} \quad (e/4K)[(3\pi/2)-1],$$

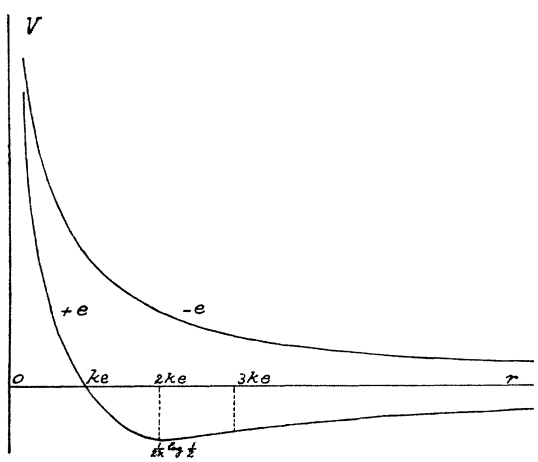

FIG. 1.

depending on whether e is negative or positive. The ratio of these two values is 1.444. Setting the value of the energy integral equal to the mass of the electron gives us the value of K, which will thus depend on the sign chosen for the charge of the electron. If this is arbitrarily taken to be negative, then we obtain $K=3.8\times 10^{4}$. There should then exist a positive particle of mass equal to 1.444 times that of the electron. A positive counterpart of the electron can also exist, but it should have a tendency to be annihilated by combining with an electron.

According to the sign of e, the potential curve takes one of the two forms shown in Fig. 1. For $e<0$, the curve has no minimum, and the force on a particle of the same sign is always repulsive. For $e>0$, there is a minimum at $r=2Ke$, and the field becomes attractive at distances smaller than $2Ke$. The force on a particle of opposite sign becomes repulsive at very small distances. With the value $K=3.8\times 10^{-4}$ we find that the field changes sign for $r=3.7\times 10^{-13}$.

Evidence for the existence of positive particles of mass greater than that of the electron occurring in the neighborhood of β-ray emitters has been found by Smith and Groetzinger.[2] A rough estimate of the mass, determined from the loss of momentum of the particle in a foil, has led the authors to a value approximately equal to 1.5 to 2 times the electron mass.[3]

It has also been recently reported in the press that charged particles of mass about three times that of the electron have been found by Auger in cosmic radiation.

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Production of Cosmic-Ray Mesons

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IT is currently believed that cosmic-ray mesons are produced in nuclear events induced by primary protons near the top of the atmosphere. The well-known difficulty of the absence of nuclear interaction by sea level mesons and the recent experiments with photographic emulsions[1] have led to the idea[2] that π-mesons, of mass 180 Mev, are the ones produced initially and that each π-meson quickly decays (10^{-7}–10^{-10} sec. lifetime) into an "ordinary" μ-meson of mass 100 Mev and a neutral recoil. An investigation has been undertaken to see whether these ideas are in quantitative agreement with actual observations on meson spectra and intensities.

It is found that there is indeed agreement if the mean free path for absorption of the primary protons is taken to be $\sim$5 cm Hg and if about half the primary energy goes to charged π-mesons, the average multiplicity being around 5 at high latitudes and increasing roughly as the square root of the primary energy.

Our analysis is based on the following argument. No meson theory has as yet proved adequate, but if one uses the general picture that a field of virtual mesons surrounds the proton and that the difference immediately after the nuclear collision between the actual and "proper" fields constitutes the meson emission, then according to Heisenberg[3] the following qualitative results are to be expected in any reasonable theory: (1) Emission is multiple and the multiplicity increases with proton energy. (2) Low energies are favored in the emitted spectrum, whose relative shape should not depend strongly on the proton energy. To put these ideas in a suitable form for computation, the following meson production spectrum, containing three arbitrary parameters, is assumed: A proton of kinetic energy E_p produces mesons whose total (kinetic+rest) energies E_m are distributed from $m_\pi c^2$ to KE_p according to a power law $E_m^{-\beta}$. The total fraction of proton kinetic energy delivered to charged π-mesons is **H**. The four parameters, K, β, **H**, and the mean free path for the nuclear process (assumed independent of E_p) are to be determined by fitting various experiments. More meaningful than the individual values of K and β is the fact that together with **H** they fix the multiplicity, which has an approximate energy dependence $\sim E_p^{\beta-1}$.

The altitude dependence of vertical particles penetrating 21 cm of Pb (assumed to be "fast" mesons only) at Los Angeles and at the equator[4] was used to fix β and K by the following procedure: A spectrum of primary protons was chosen by fitting the latitude effect for vertical radiation[5] to the usual high energy power law. The result was a power law $E_p^{-2.9}$ above 12 Bev, $E_p^{-1.5}$ between 12 Bev and 4 Bev, zero flux below 4 Bev. This proton spectrum produces a meson spectrum whose shape depends essentially only on β and K, and the shape of the meson spectrum at any altitude is sufficient to determine the relative intensities at all lower altitudes by the usual one-dimensional diffusion theory.[6] In this way the experimental equator meson curve and the Los Angeles-equator difference were used to fix $\beta=1.5\pm0.2$, $K=0.45\pm0.1$, independently of **H** and λ. This choice implies a multiplicity which increases at high energies like $E_p^{0.5\pm0.2}$ and has an average value 15**H** at the equator. A recent theoretical calculation[7] of the multiplicity of pseudoscalar meson production predicts an energy dependence $\sim E_p^{\frac{1}{4}}$.

The values of **H** and λ were fixed by experiments at higher altitudes. Schein's balloon data[8] on vertical particles penetrating 18 cm of Pb at Chicago can be extrapolated to the top of the atmosphere to obtain the total vertically incident flux, 0.10 particles cm^{-2} sec.$^{-1}$ per unit solid angle. This figure is in reasonable agreement with the bare counter rocket figure of 0.12,[9] considering that the latter may include re-entrant electrons. A calculation of the meson intensity to be expected at sea level from this incident flux and comparison with the well-known figure of 0.0074 fixes pairs of **H** and λ. The possible pairs are reduced by fitting the slope of the meson plus proton curve near the top, there being no maximum. The results are

$$4.5 \text{ cm Hg} < \lambda < 7 \text{ cm Hg},$$
$$0.6 \text{ cm Hg} > \kappa > 0.3 \text{ cm Hg}.$$

(A geometrical nuclear cross section corresponds to $\lambda\approx4$ cm Hg.) The uncertainty is considerable because of the unknown number of mesons in the slow group which can penetrate 18 cm Pb (see below).

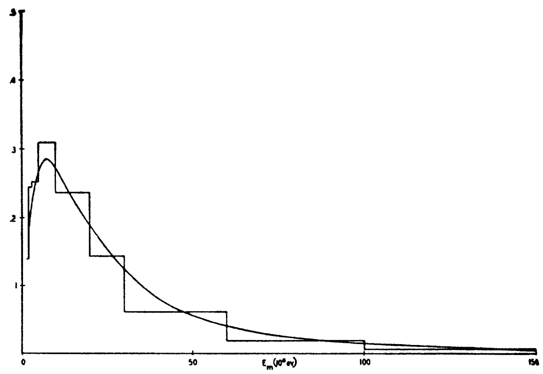

FIG. 1. Differential spectrum of mesons at sea level normalized to one particle.

As a check on the above choice of parameters, additional calculations were made of absolute latitude effect and of the meson spectrum at sea level. The results agree satisfactorily with experiment, for the latitude effect is within 20 percent and the spectrum is shown in Fig. 1, as compared to Wilson's cloud-chamber data[10] shown in blocks. The fact that the maximum occurs at a lower energy than in previous theoretical calculations[6,11] is due partly to the π-μ-decay and partly to the preference given to low energy mesons in the production process. A further test of our assumptions will come when balloon measurements of the hard component can be taken at the equator. A maximum of about seven times the sea level intensity at a pressure of 5 cm Hg is predicted.

Recent experiments [12–14] indicate that the situation is not actually as simple as assumed above. A very large number of slow mesons (kinetic energy less than 400 Mev) continues to be produced down to altitudes of about 14,000 ft. by what may be the decay of neutral particles. (All the experiments used in the above analysis fairly well exclude this slow group.) Assuming these slow mesons to be of the same variety as those observed at sea level, one finds their total energy loss throughout the atmosphere to be about equal to that of the "fast" mesons. It is therefore gratifying that our result above shows only half or less of the primary energy going immediately into fast-charged mesons.

This investigation, then, does not reveal any clear-cut inconsistencies in the proton π-μ-hypothesis, but so far rather tends to support the latter.

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